A Study of

ACID MINE DRAINAGE

With Reference To

THE DICKASON RUN DRAINAGE BASIN

Jackson County, Ohio

by

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As a Fulfillment for Geology 570
and as Partial Fulfillment for the Requirements
of a Bachelor of Science Degree in Geology.

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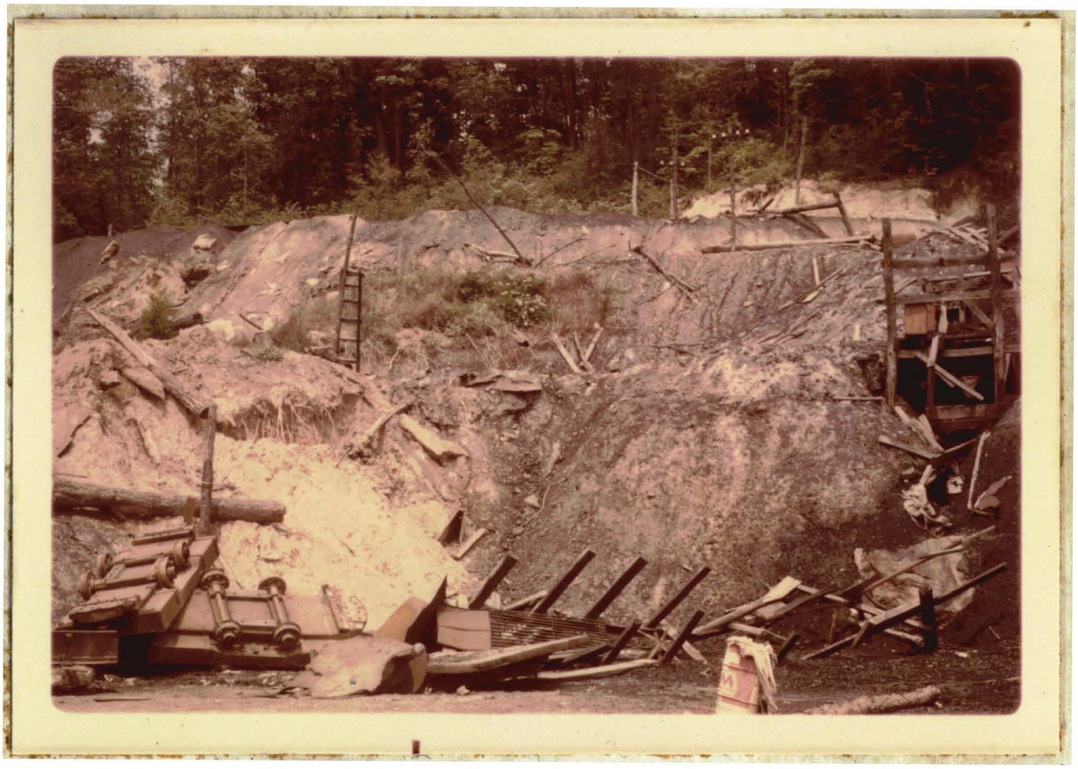
ILLUSTRATIONS

Dickason Run 100 yards upstream from its confluence with Little Raccoon Creek. Note limonite staining of the stream bed.



Abandoned underground coal mine in the Valley of Dixon Run, a major tributary of Dickason Run.

ABSTRACT

Dickason Run drains much of Bloomfield Township, Jackson County, Ohio. The stream is highly contaminated with sulfuric acid due to drainage from the numerous strip mines in the area, which have exposed the sulfur rich Clarian coal seam to atmospheric oxidation. A value of pH as low as 2.8 has been measured in tributary streams. Streams also show sulfate concentrations near 400 ppm (parts per million), iron concentrations over 2.0 ppm, and specific conductance near 1500 micromhos. Stagnant water in the mine areas have much lower pH, higher sulfate and iron concentrations, and a conductance as high as 4000 micromhos. There is no evidence of other industrial waste in the form of metal ions in the basin, and the water is free of raw sewage.

The contamination must be stopped in the near future, and one method by which this may be accomplished is by stopping the oxidation of the sulfuric material in the mines.

INTRODUCTION

In March, 1969 the author had completed an advanced course in hydrogeology at The Ohio State University, Columbus, Ohio, in which he was introduced to the problem of acid mine drainage and its effect on the water quality of the surrounding area. The author became interested in further study of this problem, and thus, elected to do individual research exploring the factors associated with the topic. The Dickason Run Drainage Basin of Jackson County, Ohio, was selected because it provides an ideal area in both size and extent of acid contamination. This basin offered an opportunity to study the complete hydrologic cycle as it related to the mine drainage. Work was begun in the spring of 1969 and continued through early autumn. This paper defines the basin, its water budget, the quality of its water in relation to mining activities, and makes suggestions to alleviate the contamination.

PURPOSE

The primary purpose of this investigation was to give the author experience in research and report writing, along with fulfilling a requirement for a Bachelor of Science Degree in Geology at The Ohio State University. It should also provide some specific information and data concerning the Dickason Run Drainage Basin.

PREVIOUS WORK

Very little work has been done on the hydrology of Dickason Run. The Ohio State Department of Mines did locate and map the mining activities of the area in the 1930's, but current records of new mining activities are not available. The U. S. Geological Survey measured stream discharge once during each year from 1951 to 1953, but this information was not published. Clifford and Snavely (1954), in their study of acid mine drainage of Racoon Creek, did mention Dickason Run as one of the major contributors of acid water to Little Racoon Creek, a tributary of Racoon Creek. However, their study of the stream was of limited scope, and virtually of little value in showing the magnitude of the contamination in Dickason Run. The most recent study of the area and its problem was conducted by Johnson (1968), another Ohio State student, who described in a senior thesis the acid water drainage of Mulga Run, which is about six miles north of Dickason Run; Mulga Run also drains into Little Racoon Creek. Mulga Run experiences similar problems to those found in Dickason Run, however, they are not quite as extensive. The geology of the entire Jackson area has been studied extensively and is published in several papers, journals, and texts (see Stout, 1916, Bownocker, 1965, Walker, 1953).

ACKNOWLEDGEMENTS

The author would like to thank the many people whose advice and consultations were sought, giving him further insight into the project. His most sincere thanks and gratitude to his advisor, Dr. Wayne A. Pettyjohn, Department of Geology, The Ohio State University, who not only advised him, but also gave him a greater insight into hydrologic problems. His appreciation to Dr. Gunter Faure, Professor of Geology, for his advice on geochemistry. Several discussions with Gene O. Johnson proved extremely helpful. The author is grateful to his fiancee, Gail Brook, to his brother, Bruce, and to his friend and fellow geologist, Bruce Hulman, for their help in collecting data, and to his father for his financial assistance. The cooperation of the Ohio and the U. S. Geological Surveys, along with the library privileges extended by the Ohio State University Water Resources Center was helpful and greatly appreciated.

METHOD OF INVESTIGATION

Since virtually no raw data were available, it was necessary to visit the site on several occasions to collect information. Since Dickason Run was the drainage basin of primary concern, it was felt that most of the data should come from this stream. However, it was soon learned that the size of the basin prohibited a thorough and comprehensive study, but most importantly, that a study of this nature would be of little value, since the tributaries are actually the original acid carriers. Dickason Run does not carry the acid directly from the mine areas, but rather is a secondary carrier, and actually starts the dilution process. Therefore, the data from Dickason Run should show how much dilution of the acid water is taking place, and the actual amount of acid being discharged into Little Racoon Creek.

In order to show better the problem of acid mine drainage in the basin, two major tributaries to Dickason Run were chosen and compared. The entire length of the streams were checked for pH changes, and the bed material was noted. In theory, it was believed that through areas of coal outcrop or mining, that the values of pH would decrease, indicating the addition of acid, but that through sandstone formations, the pH should rise due to dilution by effluent ground-water seepage. It was hoped that this method of investigating the problem whould prove analagous to the hydrology of Dickason Run.

All water samples were analyzed for their chemical content with the belief that this would further show the extent of the contamination, and to support better the pH and conductivity data. Chemical analyses of water samples were obtained with the use of a Hach Portable Engineer's

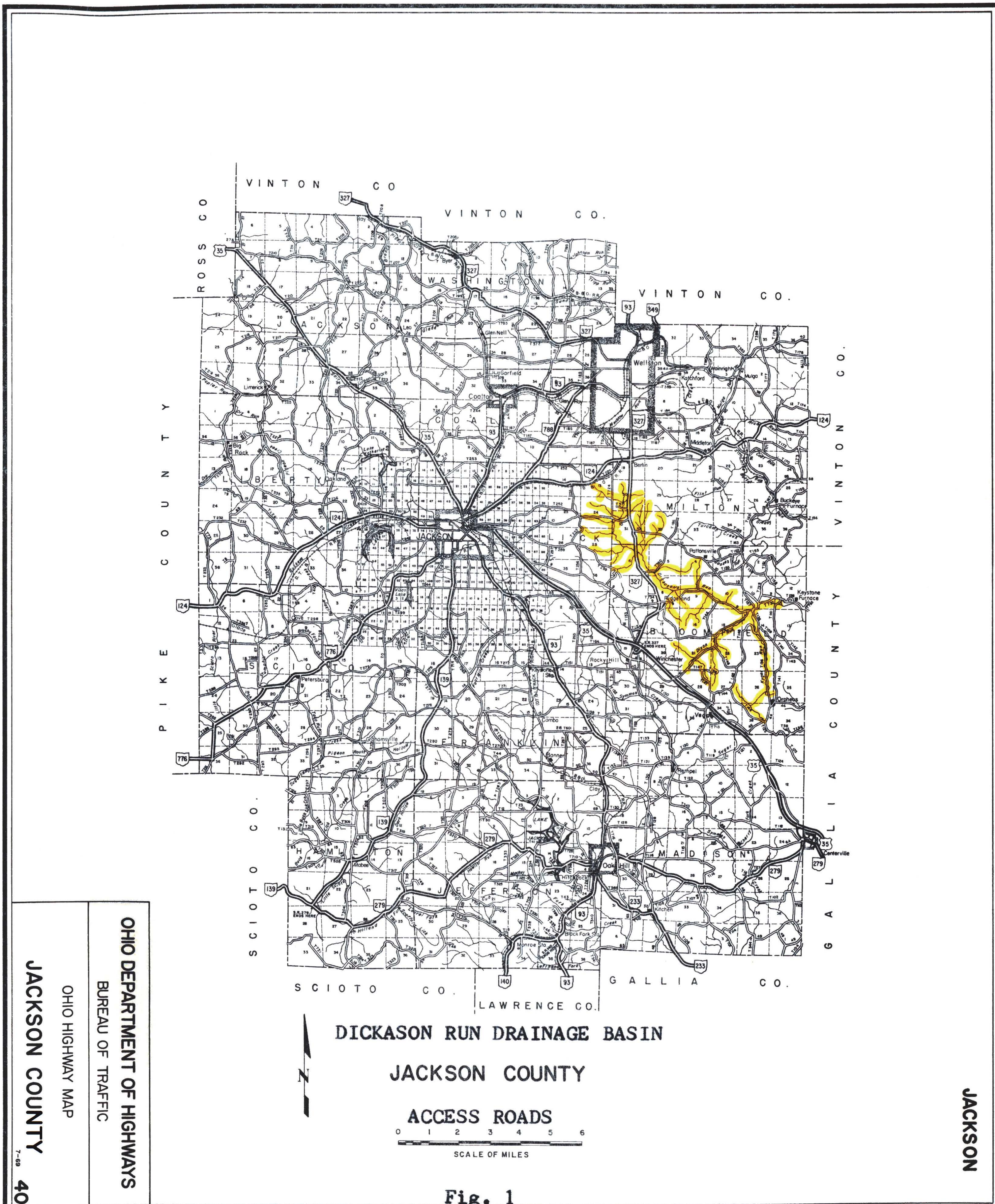
Laboratory. Portable pH and conductivity meters were also used in the study. Stream discharge was gaged by a V-notched weir, made from one-quarter inch thick plexiglass, which provided an easy means of obtaining relatively accurate discharge rates. A basin map was developed from available topographic maps.

THE GEOGRAPHY OF THE AREA

The Dickason Run drainage basin is in the northern half of Bloomfield Township, Jackson County, Ohio (fig 1). The basin is approximately 100 miles, by road, southeast of Columbus. Numerous county roads cross the basin, making it easily accessible. The confluence of Dickason Run with Little Raccoon Creek is approximately one mile west of the old Keyston Furnace in Section 12 (fig 1).

The entire area is hilly and rough, with the exception of the flat valley floors (fig 2). The soils in the area are derived from shale and sandstone. As the result of the surface topography and the type of soils, the area ranks low in agricultural production. Rather, it is better adapted to stock and fruit raising. Because of the hills, miners have found it easy to locate and remove minerals, which crop out on the hill flanks. The Lower Kittanning and Clarion 4a Coals, which are the major coal seams in the basin, have been mined since the latter part of the 19th century.

The Dickason Run Drainage Basin looks much like any other low income, rural area of Appalacian United States. Numerous abandoned or dilapidated farms and houses are scattered throughout the area. There is little industry in the basin, and most people find work in the surrounding



DICKASON RUN DRAINAGE BASIN

JACKSON COUNTY

ACCESS ROADS

Fig. 1

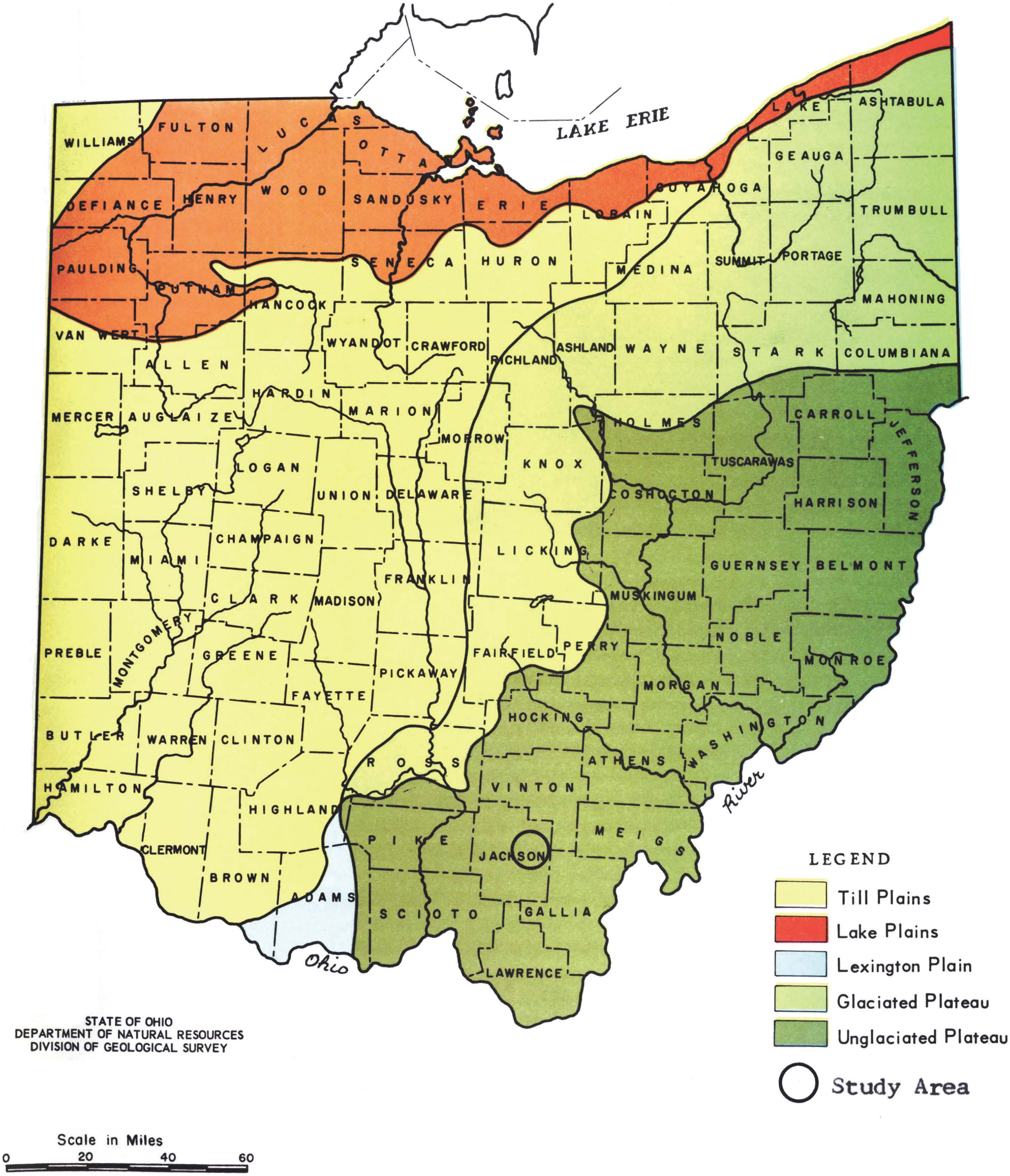


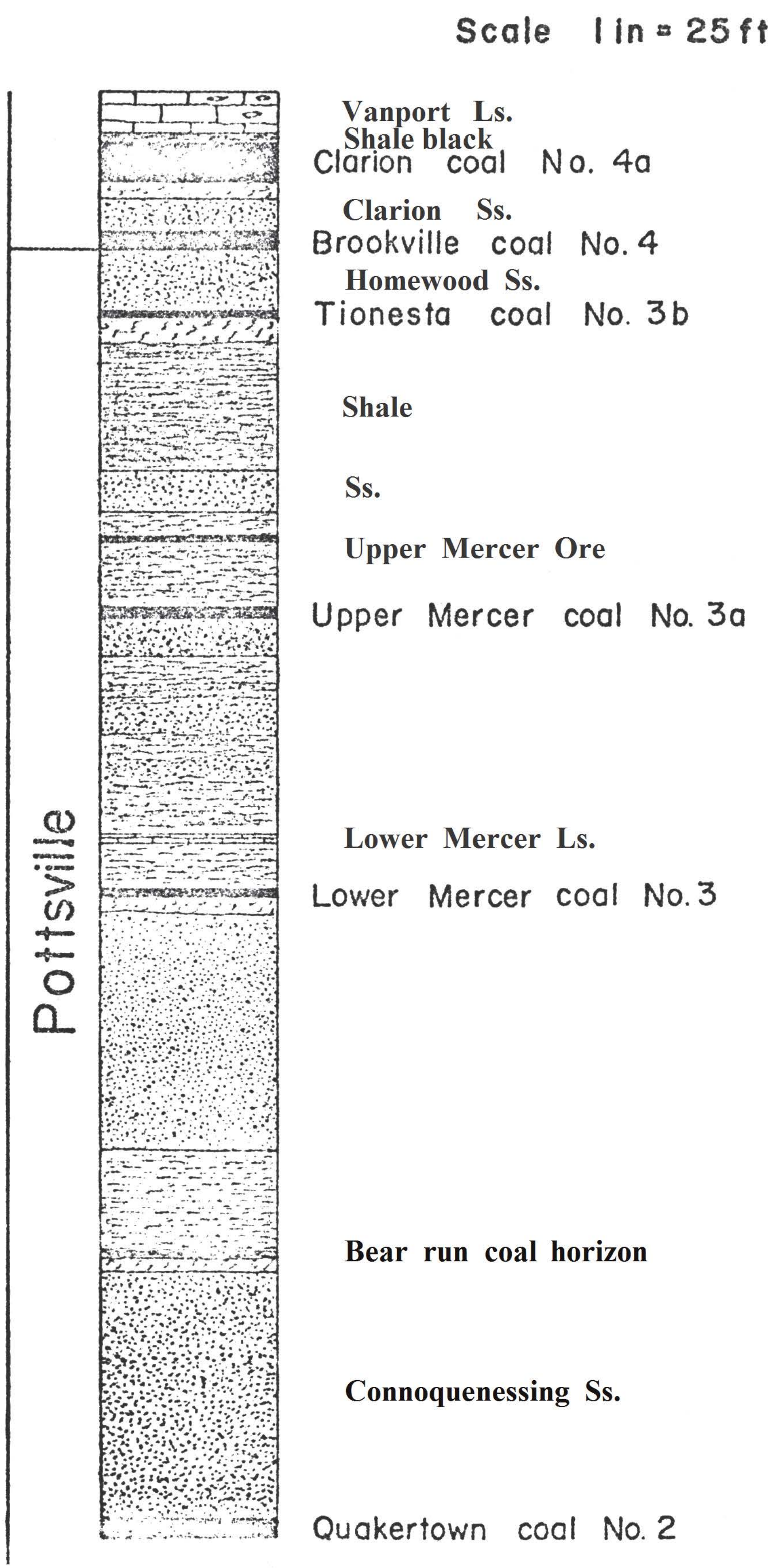
Fig. 2

PHYSIOGRAPHIC SECTIONS OF OHIO

cities. The Ohio Highway Department is currently building the Appalacian Highway across the Northern part of the area, and it is hoped that this highway will encourage industry to settle in the Appalacian Area, and thus, increase the economic standard of the residents.

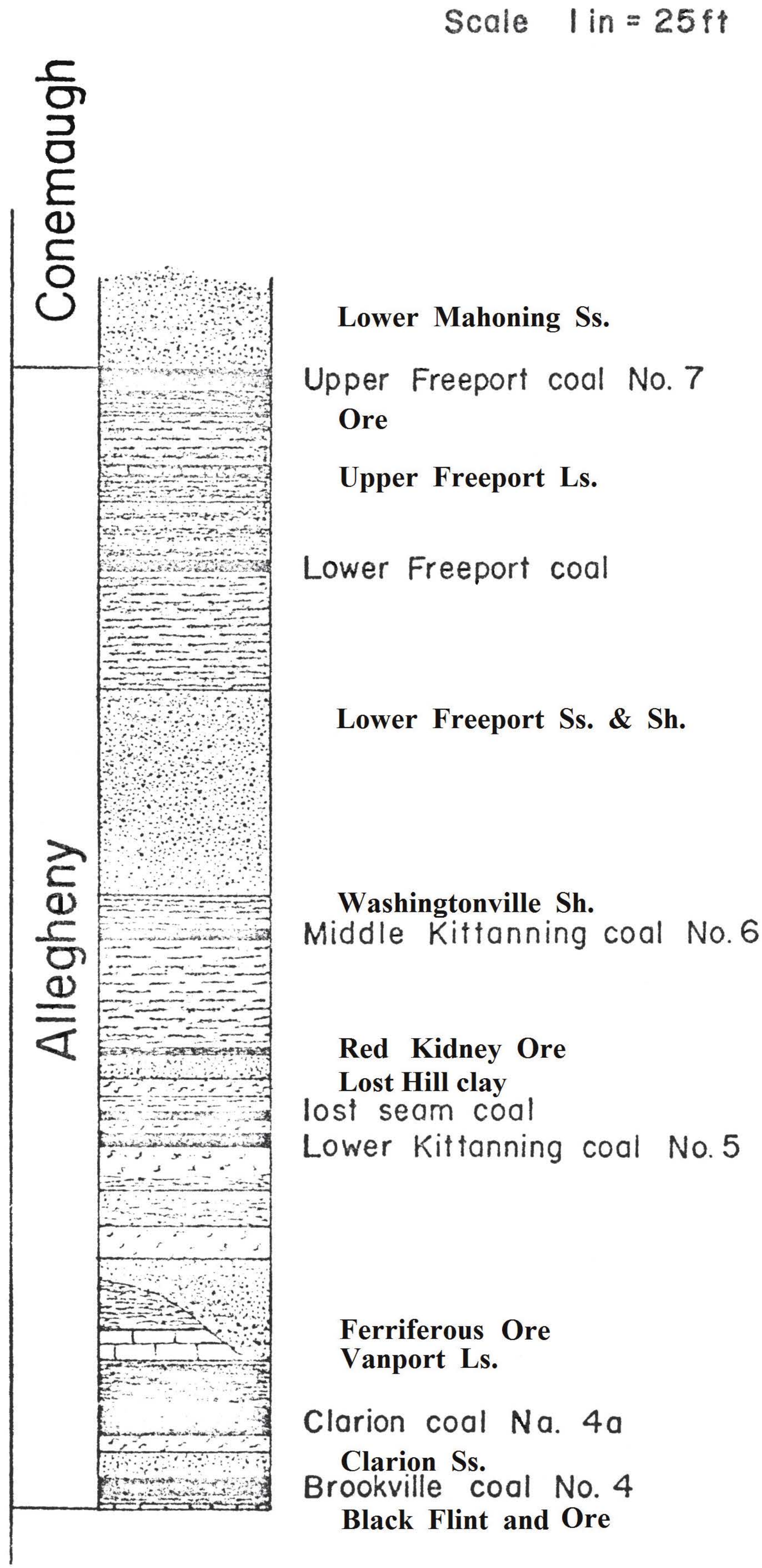
GEOLOGY OF THE AREA

The study area is part of the Appalachian Plateau, and is underlain by rocks of Pennsylvanian age (figs. 3 and 4). These rocks consist of the Pottsville, Allegheny, and the lower beds of the Conemaugh Formations. The rocks strike generally in an approximate north-south direction. The dip is about 4 to 6 degrees to the east. The rocks all consist of alternating layers of shale, sandstone, limestone, and coal. Specific outcrops in the study area were measured by Stout (1916), and are described in the appendix.

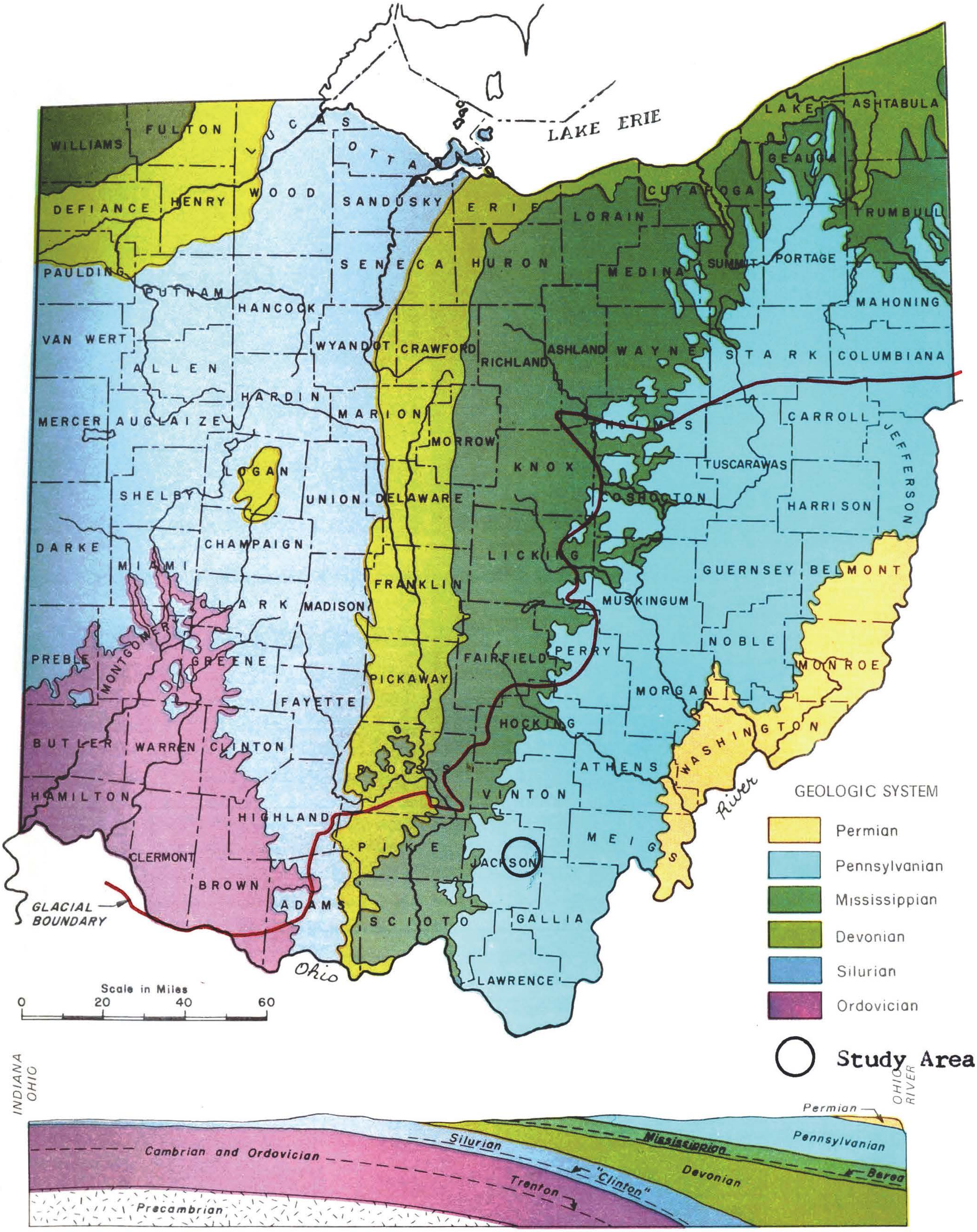


GEOLOGIC SECTION OF LOWER DICKASON RUN

Fig. 3



GEOLOGIC SECTION OF LOWER DICKASON RUN



OHIO DIVISION OF GEOLOGICAL SURVEY

GEOLOGIC MAP AND CROSS SECTION OF OHIO

Fig. 4

SYMPTONS OF ACID MINE DRAINAGE

Dickason Run flows 8.6 miles from its head waters to its confluence with Little Raccoon Creek, draining an area of nearly 26 square miles. The stream shows those symptons typical of mine drainage. The clarity of the stream enables one to see the bed in most locations, which could be deceiving to the layman who has read and heard about clear mountain streams, and the refreshing water found in them. However, the features that distinguish an acid-carrying stream from a clear uncontaminated mountain stream are numerous and worth noting. The acid-stream bed is coated with a "rust," which is actually Limonite, ($Fe_2O_3 \cdot nH_2O$), precipitated from the iron-rich water. Trees that line the banks of the stream are dead or nearly so, and often their bases are stained to a height of three to four feet by the same yellowish orange "rust" that coats the bed. This represents sediment deposited during times of high discharge, when the stream over-flowed its banks. One finds very little vegetation growing in the water, as the majority of the aquatic plants and animals have been destroyed by the acid waters. When the pH consistently falls below about 4.0, usually the only vegetation found is a strange acid-tolerant algae. The high degree of acidity results in a lack of fish in the stream. Fish kills, caused by acid mine drainage, were reported as early as 1890 in several Pennsylvania rivers (McFadden, Moulton, Berker, 1957). Similar fish kills were probably prevelant in this area of Ohio around the turn of the century.

Also present in mine drainage are high sulfate concentrations. The U. S. Public Health Service set the recommended limit for sulfate (SO_4) in drinking water supplies of 250 ppm, which is normally well exceeded in mine drainage. Although some livestock can tolerate high sulfate levels, generally any excess of 250 ppm will produce a laxative effect in humans. The limit for iron is 0.3 ppm, which is also well exceeded by mine waters. Amounts greater than this will cause staining, expecially of clothes and plumbing fixtures. Other materials usually found in significant amounts are aluminum, manganese, calcium, and magnesium. In general, mine acid waters contain high TDS (Total Dissolved Solids), which is reflected by conductivity measurements.

THE pH OF THE WATER

The portable pH meter used in this study indicates values of acidity in terms of pH rather than total acidity. It is therefore necessary to understand the derivation and meaning of various pH values (see Krauskopf, 1967).

In nature, observed pH values lie mostly in the range 4.0 to 9.0. Streams in humid regions generally show values between 5.0 and 6.5, in arid regions between 7 and 8. Soil water, especially if decaying vegetation is abundant, may have pH's down to 4 or a little lower. Ocean water normally shows a pH range of 8.1 to 8.3. Soil water and playa-lake water in deserts may have pH values of 9 or higher. The lowest recorded pH's in nature occur in solutions in contact with oxidizing pyrite or marcasite; values even less than zero have been recorded from such environments.

The pH is a measure of the hydrogen ion concentration present, which is only part of the total acidity, which indicates the capacity of the water to react with an alkaline. Also, the values obtained with the pH meter represent the total hydrogen ion present, and thus, takes into account acids not directly associated with the coal mines. For example, there is no way for the pH meter to differentiate between carbonic acid, which is present in all surface waters due to the hydrolysis of CO_2 in the atmosphere, and the sulfuric acid produced from the mine associated sulfur compounds. It will be assumed in this paper that the pH contributed by other acids is negligible.

THE CHEMISTRY OF ACID FORMATION

The formation of acid in mine drainage has been extensively investigated from both the chemical and, in recent years, the bacteriological standpoints (Clifford and Snavely, 1954). It has been shown that the acid in streams draining a coal mining area is the result of the mechanical breakdown and the chemical oxidation of the sulfuric material both in the coal and the surrounding strata. The following equations illustrate the probable method of formation of the acid (Reese, 1965):

$$2FeS_2 + 7O_2 + 2H_2O = 2FeSO_4 + 2H_2SO_4$$
$$4FeSO_4 + 2H_2SO_4 + O_2 = 2Fe_2(SO_4)_3 + 2H_2O$$
$$2Fe_2(SO_4)_3 + 6H_2O = 2Fe(OH)_3 + 2H_2SO_4.$$

In the above equations, FeS_2 is the material that provides the sulfur that is oxidized into the sulfuric acid in the streams. FeS_2 is a polymorphous mineral, forming as either pyrite of the isometric crystalline class or marcasite of the orthorhombic crystalline class.

Being of the highest symmetry crystallographic class, one expects pyrite to be the most resistant to chemical breakdown. This has been shown to be true in the laboratory, where the oxidation rates of marcasite and pyrite have been studied. In most cases, marcasite oxidizes ten times faster than the pyrite. However, this rate varies within wide limits, probably depending on entrapped gases, fineness of the sulfuric material, temperature, and other physicochemical factors.

Exposed surface area is another important factor controlling the rate and amount of acid production. In areas of extensive strip mining activity, large areas of sulfuric material are exposed to the atmosphere. Thus, when precipitation falls on the area, a large amount of oxidized material is available for conversion into sulfuric acid. The amount of annual precipitation plays an important role. Areas in the Western United States contain much sulfur rich material, but because of the low annual precipitation rate, little acid forms. Any acid resulting would be neutralized by the alkaline soils found in arid regions. Any liquid-phase present will increase the reaction rate, while oxygen partial pressure, pH, bacteria, amines, ammonia and phosphates also influence the rate. The actual rate of acid formation in coal mine drainage is greater than that predicted by atmospheric oxidation alone. It has been shown that this rate level is probably due to microorganisms which are present.

Laboratory work with both sterilized and innoculated coal samples show that microorganisms play a part in the breakdown of sulfur. The innoculated samples of coal show decided increases in the quantity of soluble sulfur present, compared with that found in similar samples, which had been sterilized but not innoculated (Clifford and Snavely, 1954). Bryner and Jameson isolated the iron and sulfur oxidizing bacteria Thiobacillus thiooxidans and Thiobacillus ferrooxidans respectively. Not only did these microorganisms increase the oxidation rate of the FeS_2 in the laboratory, but were also isolated from actual mine waters. Ferrobacillus ferrooxidans were also isolated and it was reported that they influenced the oxidation of marcasite, sulfur balls, and iron with no effect on pyrite. It must be realized that there is still considerable disagreement as to the effect and extent of microorganism influence.

ENVIRONMENTAL STABILITY of FeS_2 as EXPLAINED by Eh and pH

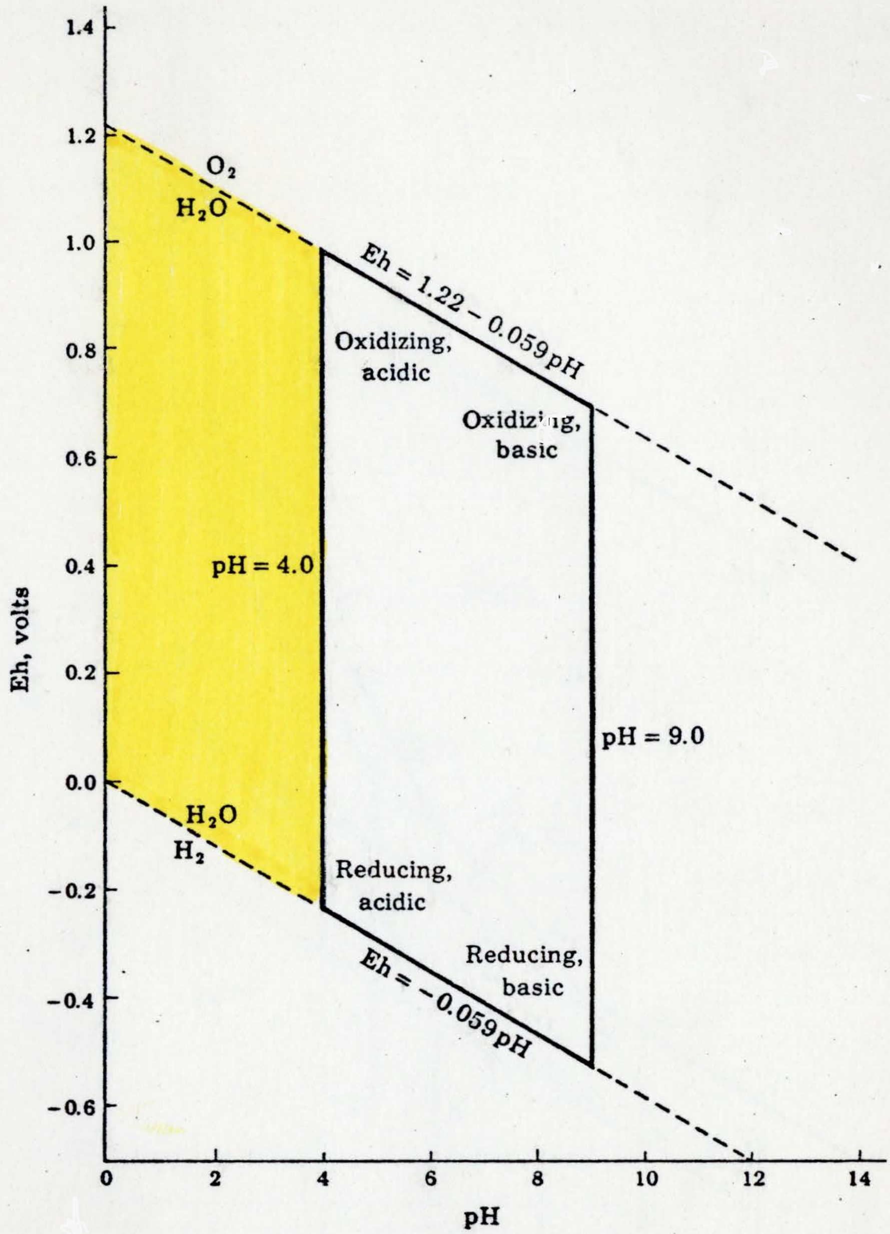
It is not the objective of this paper to go into a detailed explanation concerning the use of Eh-pH diagrams to explain geological phenomena. Further information and discussion can be obtained from Solutions, Minerals, and Equilibria, by R. M. Garrels and C. L. Crist. Most of the following discussion and the Eh-pH diagrams were taken from Krauskopf (1967).

The redox, or oxidation potential, is termed by geochemists as the Eh, and is applicable to potentials of individual half reactions. Redox potential in many ways is analogous to pH. It measures the ability of
oxidized - lose e^- reduced - gain e^-
an environment to supply electrons to an oxidizing agent, or to take up electrons from a reducing agent, just as the pH of an environment measures its ability to supply protons to a base or take up protons from an acid.

If Eh values are plotted against pH values, the usual limits of Eh and pH found in near-surface environments can be outlined (fig. 5). In the diagram, the usual range is represented by a parallelogram, and acid mine drainage conditions occur to the left of the parallelogram or at pH values usually less than 4.0.

Garrels and Christ used the Nernst equation to calculate the various stability fields for common iron minerals (fig. 6).

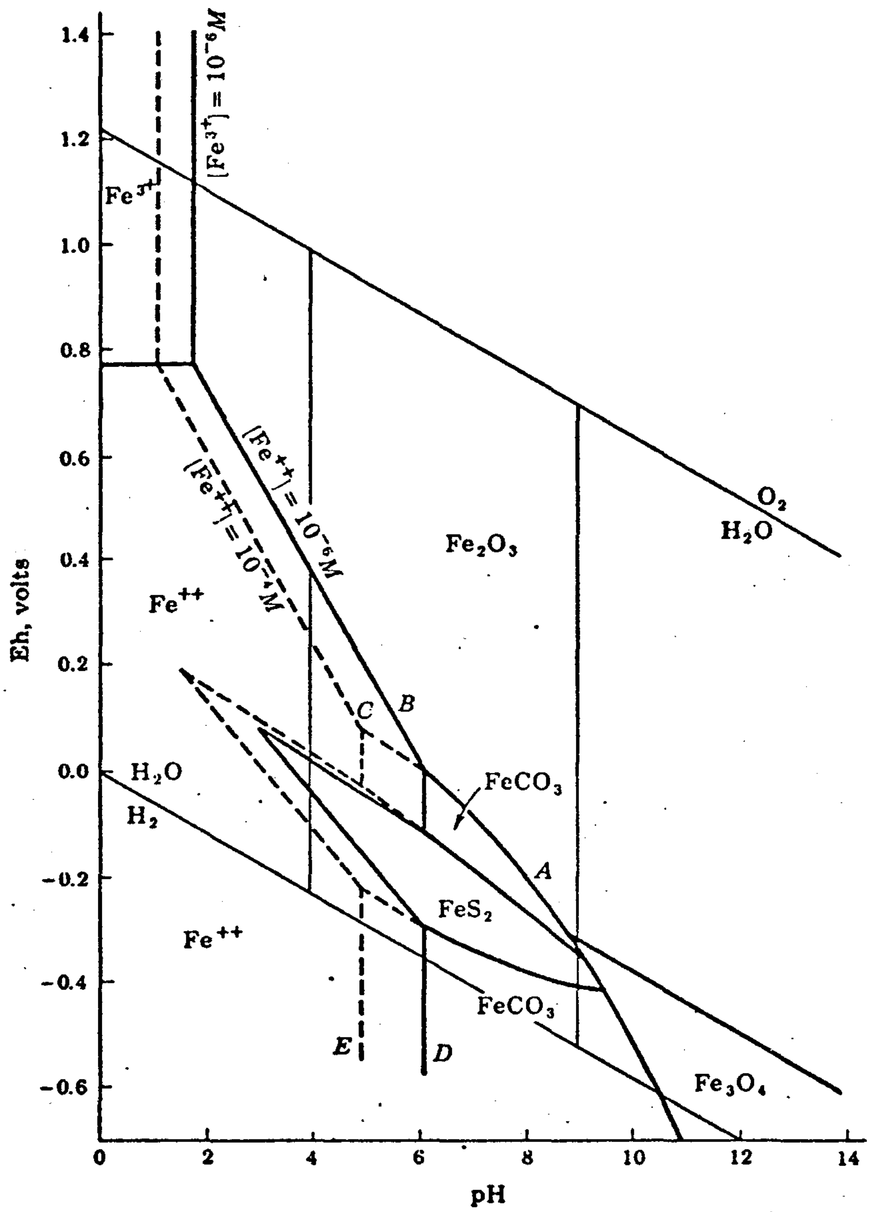
The diagram shows that FeS_2 is stable in reducing environments, either acidic or basic. If the pH is lowered, which is the case in mine acid waters, the FeS_2 will become unstable and be converted to Fe^{++}, the stable form of iron at low pH values. Similar results can occur if the Eh value is changed or both the Eh and pH values are changed. This is merely a thermodynamic interpretation, and does not consider or predict the rate at which this conversion takes place.



Framework of Eh-pH diagrams.
From Krauskopf, 1967

Conditions of Acid Mine Drainage

Fig. 5



Eh-pH diagram showing stability fields of common iron minerals. From Krauskopf, 1967

Solid field boundaries on left side of diagram are for total dissolved iron equal to $10^{-6}M$, dashed lines for $10^{-4}M$.

Fig. 6

THE WATER AND ITS QUALITY

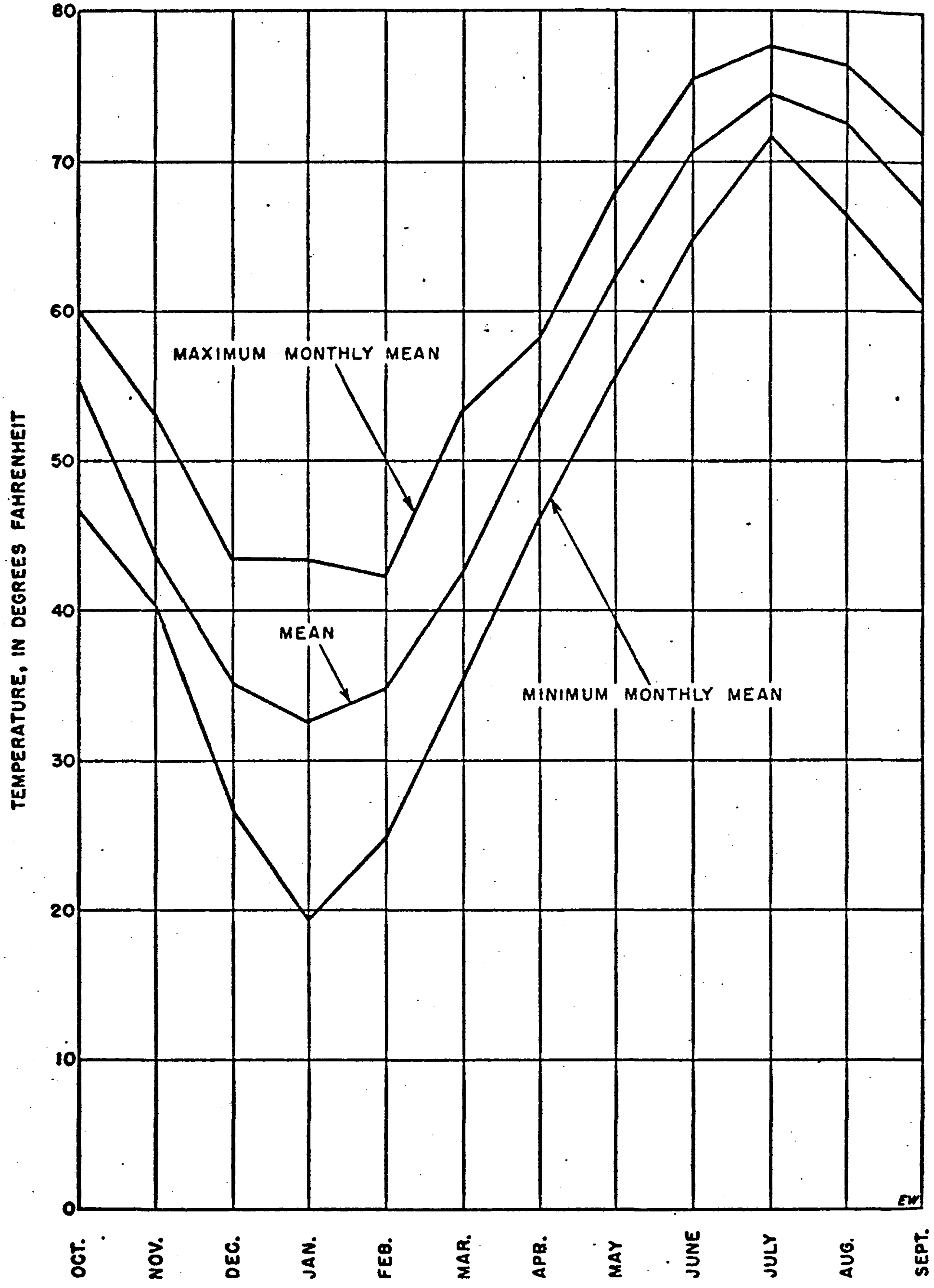
The initial source of water to a basin is precipitation. Not all of the precipitation falling on a basin ends up in the streams; some is intercepted by trees, buildings, and other objects, and consequently, evaporated. Some infiltrates to become groundwater, and some is transpired by plants. That water which enters the streams is termed runoff.

In order to determine the amount of precipitation falling on the Dickason Run drainage basin, the author placed a series of raingauges throughout the area. Each guage consisted of a chemical test tube into which one-half inch of S.A.E. 5 weight motor oil was placed. When water entered the tubes, the oil would rise or float on the more dense water. Measurement of the oil displacement would give the total precipitation for the elapsed time period. Unfortunately, the guages were tampered with, so no precipitation data was obtained by this method. Thus, the author turned to published data for the Jackson County are. It is reasonable to assume that these data will accurately reflect the precipitation records for the Dickason Run Basin.

The average annual precipitation for the 25-year period (ending in 1946) measured at Jackson, is 39.83 inches. The average annual temperature is 53.7 degrees (Walker, 1953). Figure 7 reflects the mean, maximum mean, and minimum mean monthly air temperatures for this same time period. The diagram shows the time when ice may form on the water, thus hindering water treatment operations. Figure 8 shows the precipitation by months for the station at Jackson with the variation of the maximum and the minimum from the mean. Although the precipitation is relatively constant over the twelve month period, actual stream discharge data do not reflect this consistency.

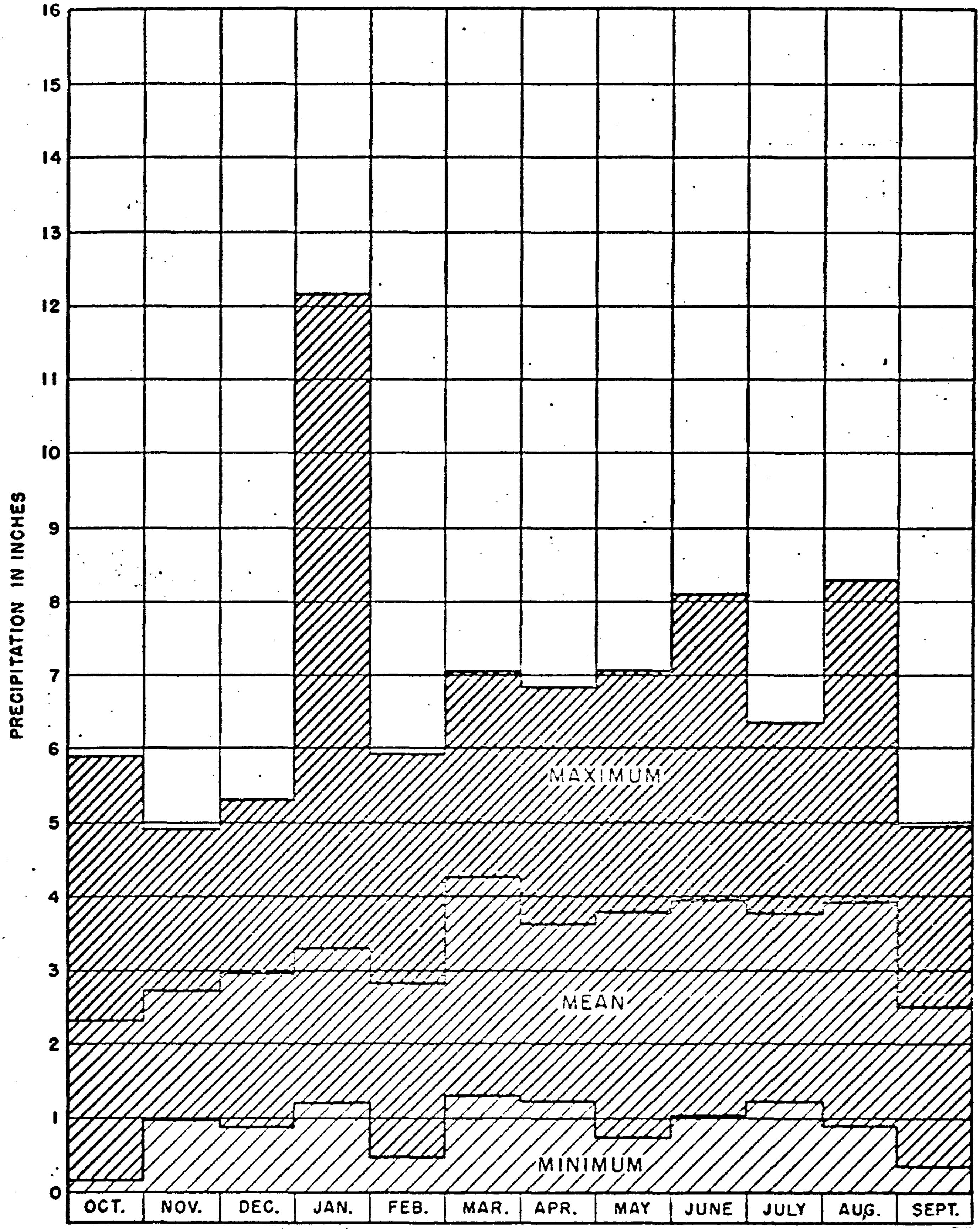
Dickason Run, along with the majority of streams in Jackson County, is not of sufficient size to handle large discharges. Since it is in an area of low permeability, large amounts of water will runoff in a short period of time. Most of the tributaries are dry during the late summer because there is no availible ground water to sustain their flow. The flashy stream has no flow during much of the summer and early fall, but the stream stage rises rapidly during any time of precipitation.

Because of this type of drainage, it would be difficult for industry to operate in the area if they were to depend on surface supplies, unless they developed some sort of upground reservoir system to assure continual water supplies. Also, acid is rapidly carried into the streams from the mines in the area, because only a minimal amount infiltrates.



Air temperatures at Jackson, 1921-1946

Fig. 7



Monthly precipitation at Jackson, 1921-1946

Fig. 8

Ground water in the area is generally not obtainable in large quantities from single aquifers. The Mississippian and Pennsylvanian sandstone layers in Jackson County are only moderate water-bearers, because of the high degree of cementation or poor sorting, or both (Walker, 1953). The amount of water that may be obtained from wells drilled close together can vary greatly, however, generally only about 10 gpm (gallons per minute) can be obtained from single wells in the consolidated rocks. The area around Dickason Run, therefore, is considered "poor" in terms of ground water development (fig. 9). Generally, amounts of 1 gpm, or less, are obtained from the underlying consolidated rocks (Walker, 1953). The locally derived alluvium along Dickason Run can supply moderate amounts of water to shallow wells. Deep wells, screened through several aquifers, might produce larger well yields. The quality of the ground water varies, but is usually high in iron, generally well exceeding the 0.3 ppm limit set by the U. S. Public Health Service.

The surface runoff in the basin is typical of most mine-drainage waters. In the course of five visits to the basin, the data obtained did not show any significant variation. The pH at the mouth of Dickason Run, was generally in the range 3.2 to 3.4. This value did drop in areas of coal mining. In these areas, the Clarian 4A coal is exposed,

PROBABLE WELL YIELDS

From Walker, 1953

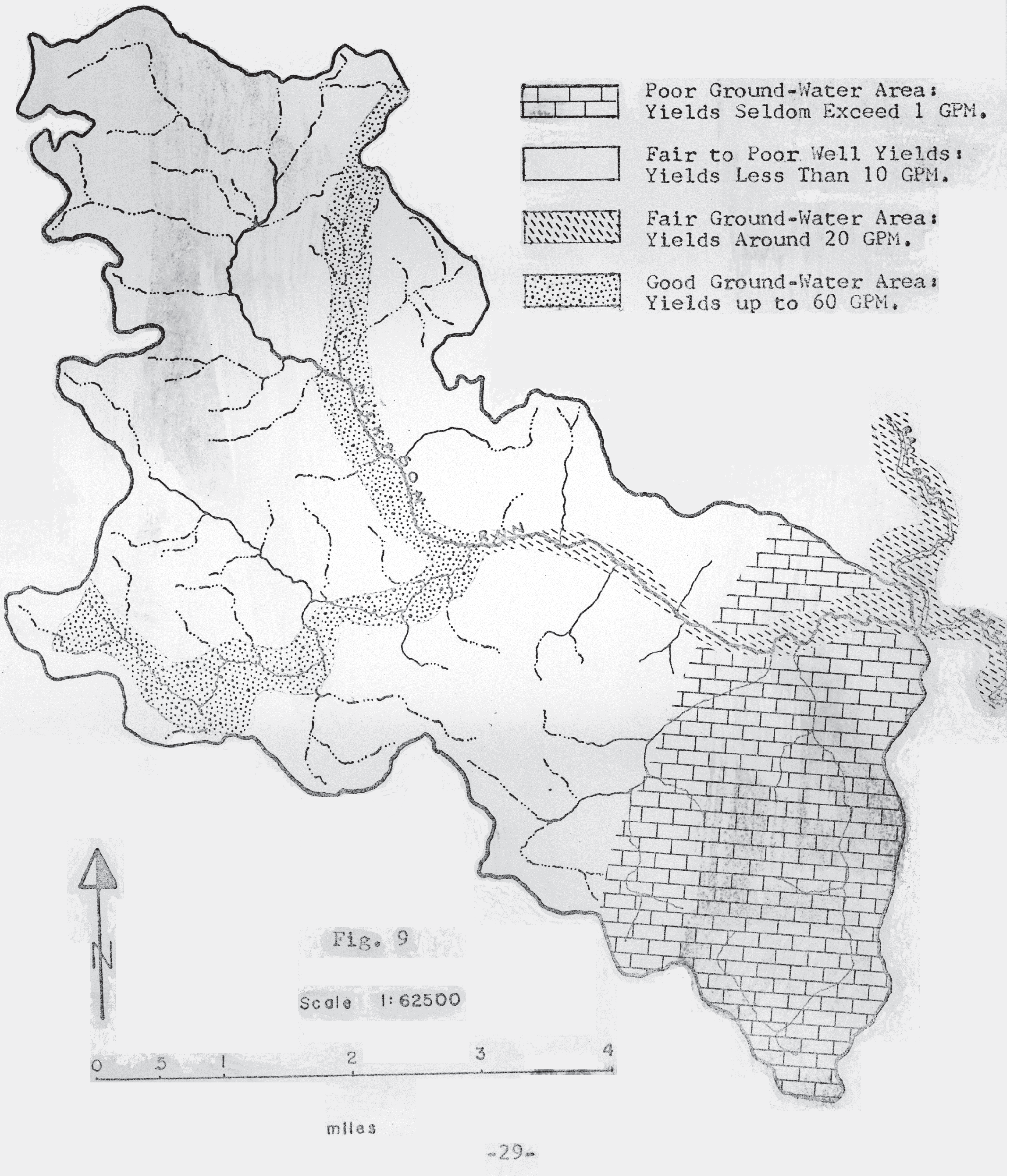


Fig. 9

Drainage from current mining operations of the Rose Coal Company. The water enters Dickason Run about one-third mile upstream from its mouth.

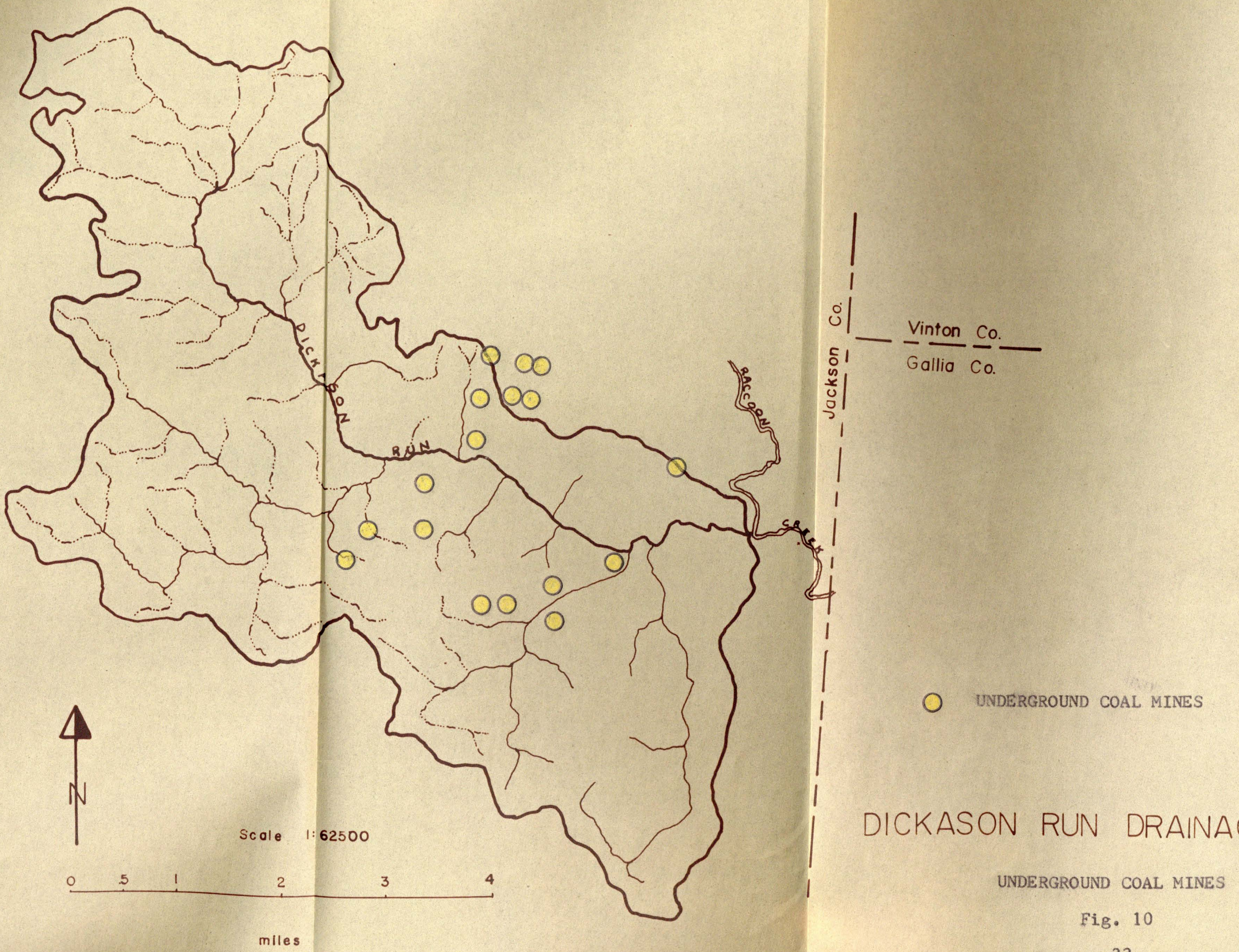
and contributes large amounts of acid to the streams. For example, the drainage from a currently active mine owned by the Rose Coal Company, showed pH values below 3.0, with specific conductance exceeding 2000 micromhos. Sulfate and iron tests were not performed due to the limiting maximum value factors attributed to the Hach kit. Similar mining situations are apparent throughout the basin.

Dixon Run was checked periodically over its length, but the pH remained virtually constant. The stream flows through an area of alluvial sand and gravel, and an abandoned strip mine parallels the stream's water divide. In order to maintain the pH at a constant level, and the stream flow several days after any precipitation, it is believed that the alluvial sand and gravel is serving as an aquifer in which the groundwater flow is from the mine to the stream. In contrast, Kyger Run, located one stream north of Dixon Run, had a pH of 6.6, or a neutral value. Kyger Run has been mentioned in several papers as an acid stream, indicating that any acid in Kyger Run must come immediately after rain fall, rather than being carried in the ground water. There is not enough ground water discharge into Kyger Run to change the pH appreciable.

At the mouth of Dickason Run, the pH was found to be slightly less than 4.0 reflecting considerible dilution of the acid. Sulfate concentrations always exceeded 300 ppm and iron was over 1.8 ppm. The total dissolved solids were high, with the specific conductance of 580 micromhos.

On May 23, 1970, the conductivity was measured in Kyger Run, Dixon Run, and the lower half of Dickason Run. Due to faulty equipment, the pH was not measured. However, recalling the equation for acid formation, one realizes that in regions such as these, increased total dissolved solids should represent decreased pH values, although no conversion of conductivity to pH is availible. The area had experienced the usual spring rains during the previous five days, so all streams had substantial discharges. The temperature on this day was near 80°F, and the relative humidity was high, thus showing favorible conditions for the formation of sulfuric acid.

Kyger Run is the first major tributary upstream from the mouth of Dickason Run (fig. 10). It flows through a narrow valley, usually less than a quarter mile wide. The valley walls are very steep in places where bedrock crops out, but usually have a lesser slope in most areas. The vegetation cover is dense, and some lumbering operations are actively being pursued. There is virtually no mining in the Kyger Run sub-basin. The stream has a well defined channel and meanders across most of the valley floor. Its depth is usually less than two feet and the width varies from about two to five feet.



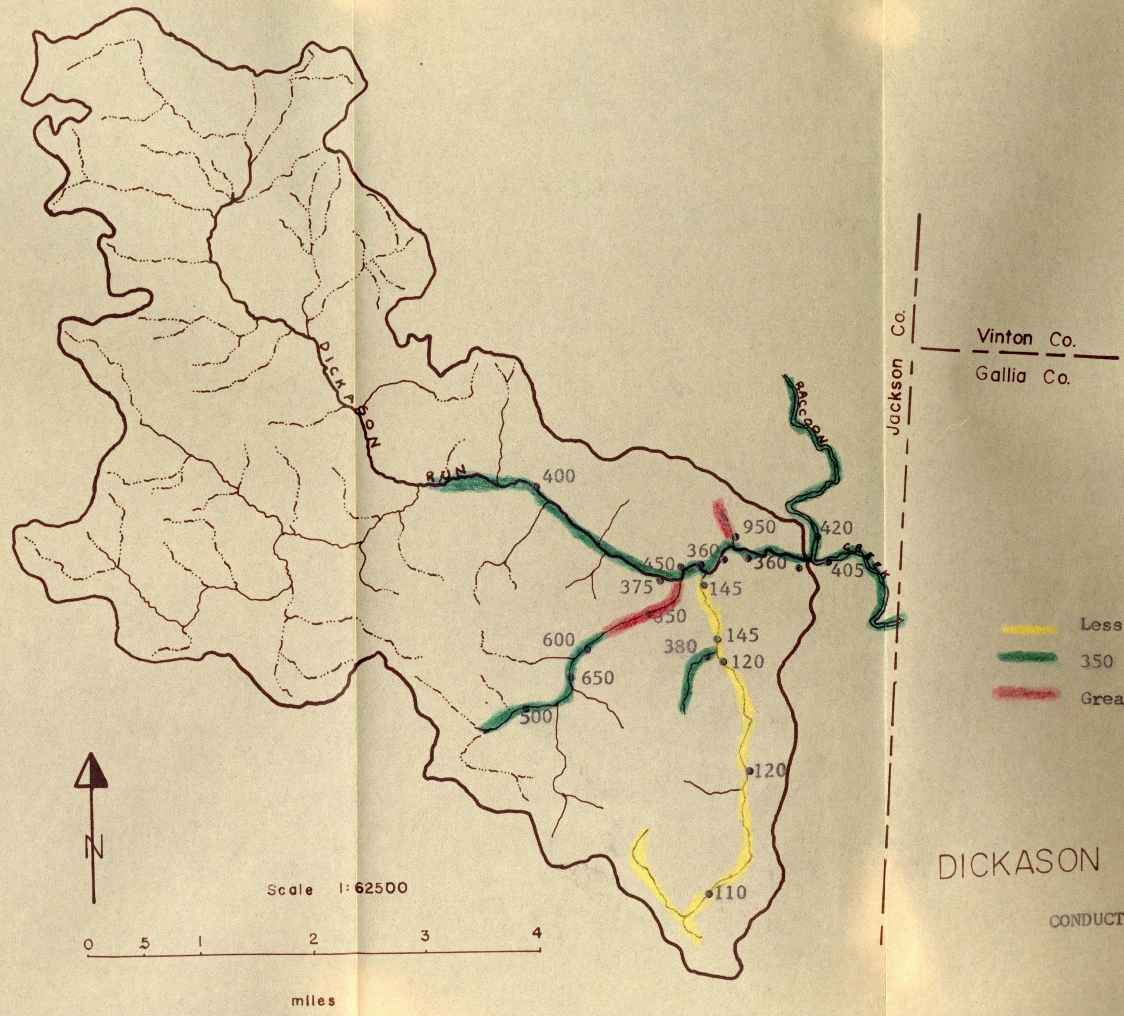
DICKASON RUN DRAINAGE BASIN

UNDERGROUND COAL MINES

Fig. 10

The quality of the water in Kyger Run is good. The conductivity at the mouth was 145 micromohs, and in the upper reaches declined to a low of 110 (fig. 11). There was only one major change in the conductivity, and that was from 120 to 145. This change was due to additional discharge from a small tributary that had conductance of 380. It is believed that this tributary drains the Eastern side of a strip mine, which parallels Dixon and Kyger Runs, accounting for its high conductivity. The pH at the mouth of Kyger Run on October 11, 1969, was 6.6 and the concentrations of sulfater was 120 ppm and iron was 0.15 ppm, reflecting the moderate quality of the stream. In addition, the good quality, for this area, is indicated by the presence of fish in the upper part of the stream. This is the only stream in the area where fish were found, elsewhere, the water is too mineralized and the pH too low to support aquatic life.

Dixon Run, just west of Kyger Run, meets Dickason Run about a half mile up stream from Kyger Run. The stream valley is similar to that of Kyger Run, with the striking exception that the Dixon Run valley shows the effects of mining operations. Vegetation is not dense and there is extensive evidence of tree kills throughout much of the basin. There is limonite staining on the stream bed and the rocks below coal mines. No fish, and very little aquatic vegetation are present in the stream waters.



Less Than 350 Micromohs

350 to 700 Micromohs

Greater Than 700 Micromohs

DICKASON RUN DRAINAGE BASIN

CONDUCTIVITY FOR MAY 23, 1970

Fig. 11

Conductivity of 500 was found in the upper parts of the Dixon Run sub-basin, reflecting contamination from some mining activities. The value increases to 650 as the stream flows past an abandoned shaft mine (fig. 11), but decreases to 600 owing to dilution from an uncontaminated tributary just down stream from the mine. The only other increase in conductivity was to 850 as again the stream passed another mining area. The stream enters Dickason Run with this conductivity and a pH of about 3.2. From limited data of this area, it can be seen that sulfates are well over 300 ppm and iron is about 2.6 ppm (Appendix).

The effects of Dixon and Kyger Runs on the water quality of Dickason Run are shown in figures 11, 12, 13, and 14. About three miles upstream from the mouth of Dickason Run, conductivity was 400, probably reflecting the mining activities up basin. Just upstream from Dixon Run, conductivity was 375, but downstream it increased to 450, because of the highly contaminated waters of Dixon Run. Downstream from the confluence of Kyger Run and Dickason Run the conductivity drops to 360, and it maintains this value until it reaches Little Raccoon Creek. A one foot wide drainage ditch from the Rose Coal Company showed a conductivity of 950, but this had no measurible effect on Dickason Run due to dilution. Numerous other drainage ditches are present, but because of there extreamly low discharge, they are diluted by the larger streams.

pH Values

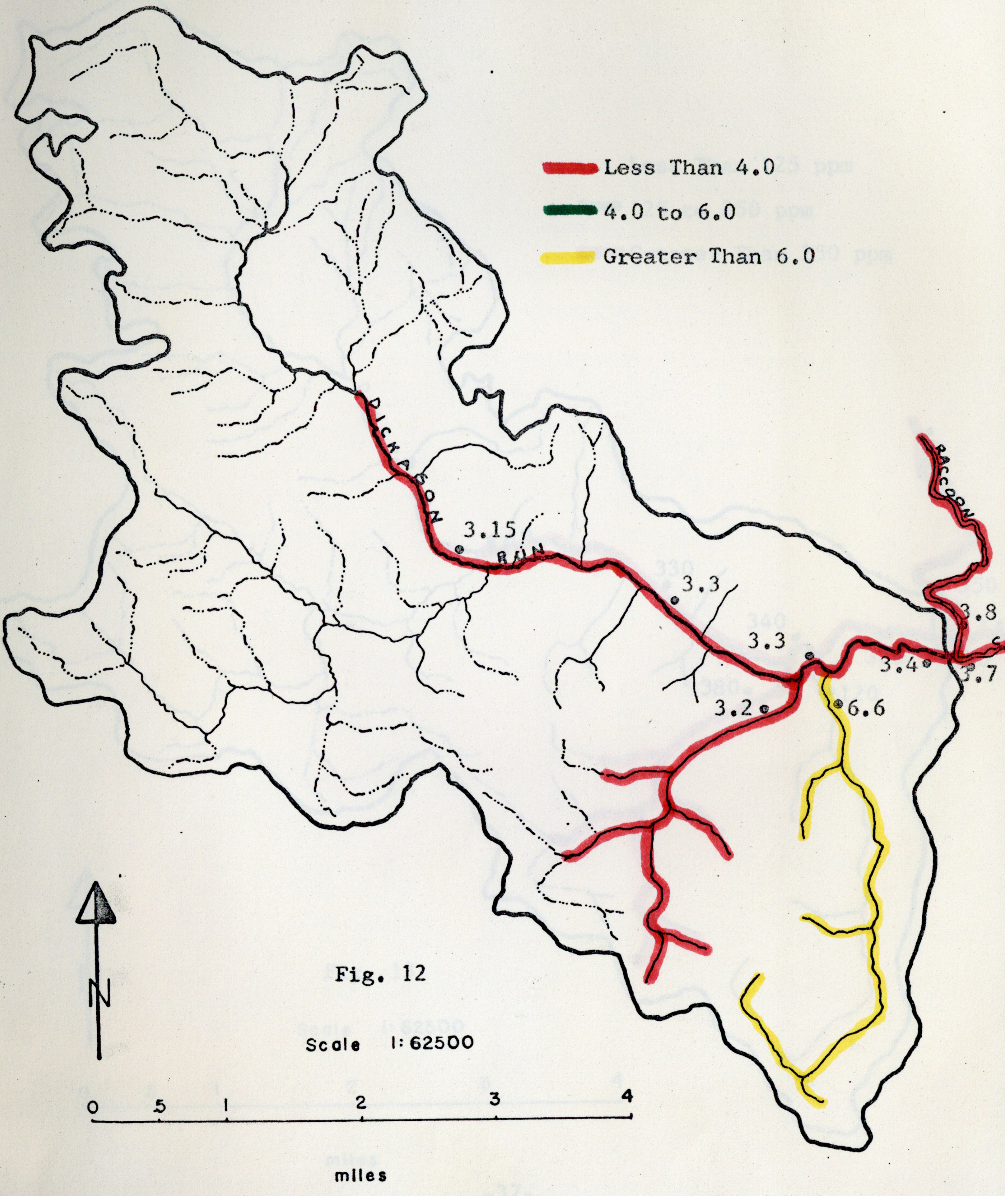


Fig. 12

SULFATE CONCENTRATIONS

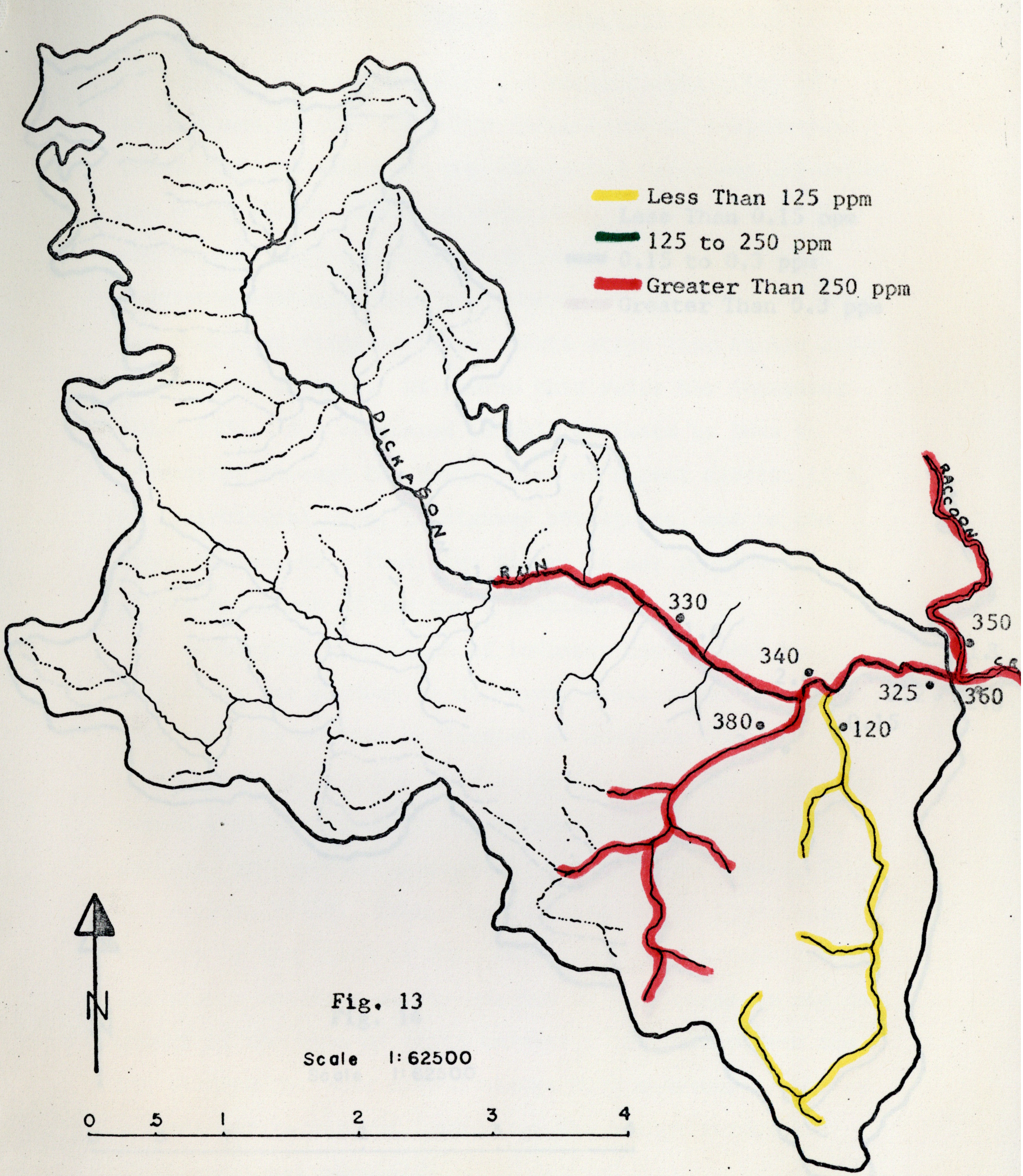


Fig. 13

IRON CONCENTRATIONS

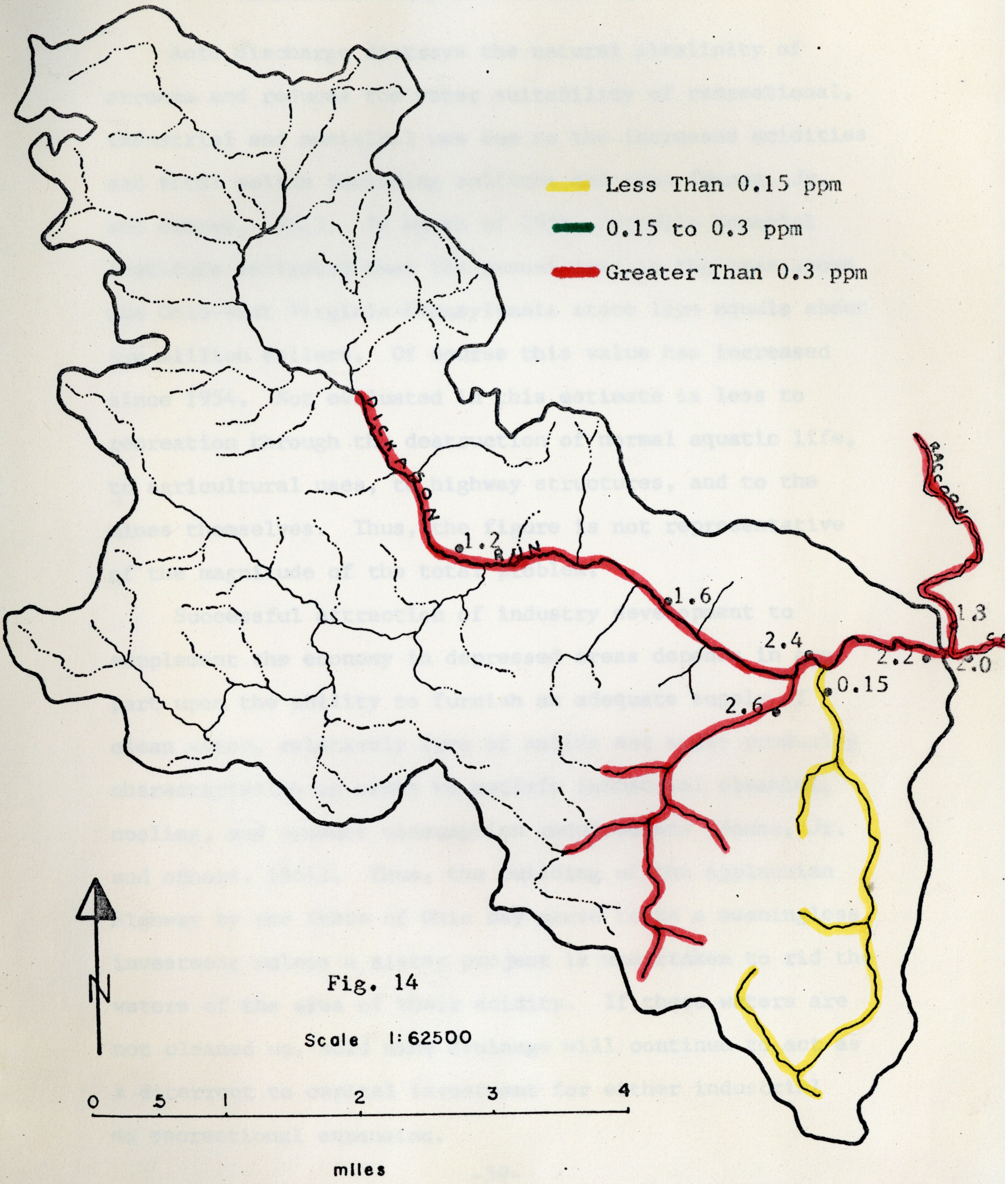


Fig. 14

DETRIMENTAL EFFECTS OF ACID MINE DRAINAGE

Acid discharge destroys the natural alkalinity of streams and reduces the water suitability of recreational, industrial and municipal use due to the increased acidities and total solids including sulfates and iron (Hanna, Jr. and others, 1961). In March of 1954, Battelle Memorial Institute estimated that the annual loss in the area above the Ohio-West Virginia-Pennsylvania state line equals about two million dollars. Of course this value has increased since 1954. Not evaluated in this estimate is loss to recreation through the destruction of normal aquatic life, to agricultural uses, to highway structures, and to the mines themselves. Thus, the figure is not representative of the magnitude of the total problem.

Successful attraction of industry development to supplement the economy in depressed areas depends in good part upon the ability to furnish an adequate supply of clean water, relatively free of solids and scale producing characteristics in order to satisfy industrial cleaning, cooling, and product consumption requirements (Hanna, Jr. and others, 1961). Thus, the building of the Applachian Highway by the State of Ohio may prove to be a meaningless investment unless a sister project is undertaken to rid the waters of the area of their acidity. If these waters are not cleaned up, acid mine drainage will continue to act as a deterrent to capital investment for either industrial or recreational expansion.

Coal dump area in the Dixon Run Drainage Basin

AN ANALYSIS OF METHODS OF RECLAIMING DICKASON RUN

Strong state laws are being, or have been enacted, in most states to control pollution from surface mining. Unfortunately, there exists abandoned mining areas in the Dickason Run Basin, and throughout the Appalachian Area, that continue to pollute the streams with acid. These areas are either not governed by new mining laws, or if these laws do apply, they are not enforced. Thus, there has been considerable basic research, and methods to control and possibly to eliminate the undesirable acid in mine drainage are being developed.

Neutralization of acid mine drainage involves the addition of an alkali compound such as limestone to the contaminated waters, thus raising the pH. This process was realized as early as the 1920's. Since that time, numerous experimentors have set up pilot studies; however, presently, none of the results from the studies have proven conclusive. The equation representing neutralization of acid with limestone ($CaCO_3$) is:

$(CaCO_3) + H_2SO_4 = CaSO_4 + H_2O + CO_2$ (Hill, 1968).

Limestone + Sulfuric Acid = Calcium Sulfate + Water + CO_2.

According to Clifford and Snavely (1954), an estimate of the annual acid load to be neutralized would be of primary importance in determining the cost of reclaiming a problem basin. The average daily acid load could be calculated as follows:

(free acidity, ppm H_2SO_4) X (discharge rate, cfs) X (0.0027) = tons of H_2SO_4 per day.

The constant 0,0027 is a conversion factor.

The United States Department of the Interior published a method for calculating the cost of alkali agents (Hill, 1968). It defines basicity as the grams of calcium carbonate equivalent per gram of alkaline agent. The basicity factor is a useful tool in comparing the cost of alkali agents. The Interior Department compares three such agents as follows:

AGENT	BASICITY FACTOR	PRICE dollars/ton	COST dollars/ton basicity
Lime (CaO)	1.78	14	$ 7.86
Limestone ($CaCO_3$)	1.00	5	5.00
Soda Ash (Na_2CO_3)	.94	31	32.98

Thus, by knowing the tons of H_2SO_4 per day and the cost of the alkali in dollars per ton, their product estimates the daily cost of neutralization. Other costs which must be included are those for construction of the treatment plant, maintenance, personel, etc. It should be obvious that the cost for a small basin, such as Dickason Run, would be prohibitive.

Another problem associated with acid neutralization programs is the disposal of the sludge byproduct. The rate at which sludge settles is important, for this sludge must be trapped and then disposed of. If the rate is too fast, which is usually the case, the sludge will coat the alkali material placed in the treatment device, and thus, the reactivity rate between the acid and alkali material will drop to zero. When limestone is used as the neutralizing material, the sludge formed is $CaSO_4 + 2H_2O$, or gypsum. It has been suggested by Dr. Gunter Faure, Ohio State University Department of Geology, that this sludge might be used to manufacture plaster board. With the proper design, a treatment and byproduct manufacturing project could be incorporated into a single operation. No further work has been done with this hypothesis.

Raising the pH of a stream from an acid level to a more neutral level is not the only requirement for treatment of mine drainage (Hill, 1968). A neutral stream which retains its high iron concentration is still not acceptable to the U. S. Public Health Service. The easiest procedure for iron elimination involves the use of an oxidizing agent such as potassium permanganate, although other methods suggested include: precipitation of iron by the addition of an alkaline agent, electrolysis of iron, aeration-filtration or aeration-settling, ultrasonic energy, ozone oxidation, and irradiation and photooxidation (Hill, 1968). Other methods for the treatment of mine drainage suggested and currently under consideration and research are: ion exchange, reverse osmosis, distillation, electrodialysis, crystallization (freezing), biological treatment, and mine sealing. Mine sealing has been virtually unsuccessful because of the difficulties in completely sealing off the mine.

Gene O. Johnson (1968) suggested that the answer to the acid mine drainage problem of Southern Ohio is to strip the Clarion Coal and associated bone shale and then consume the coal for a mass consumption-low quality use such as a steam power plant. In theory, such a project may be feasible, but it seems rather doubtful that a coal company would bring expensive equipment back into an already abandoned mine to process the remaining coal. Economically such a project obviously is not profitable, unless governmental financial incentives are used. Even more important, it is the belief of this author, that such a program may eliminate stream pollution, but the burning of such low grade, high sulfur coal would contribute to air pollution. More research must be done before such a project is undertaken.

The answer to the acid mine drainage problem of Dickason Run and that of surrounding basins is two fold. First, strict state laws and their enforcement should be initiated immediately to stop any further acid drainage areas. This would require all strip mining activities to include a program of reclamation approved by the state. Thus, all exposed sulfuric material would be buried, stopping the oxidation process. Second, the state should enact their right of eminent domain in cases where owners will not reclaim already abandoned mine areas. It will become the responsibility of the state to reclaim the area, and then possibly consider turning these areas into state recreational or wildlife preserves. By reclaiming the land and water and putting it to positive use, the state would thus upgrade the area and make it attractive to new industry and population.

These measures may seem strict. However, the contamination caused by acid mine drainage is a very real and serious problem that must be solved in the near future, or the basins involved will continue to decline economically.

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APPENDIX

Xerox Copies of Actual Well Logs From Stout's
Studies in the Dickason Run Drainage Area

Stout 1915

File No 4286
Wilkesville coal
X. 2,068,700
Y. 368,800

Section 416

Up road of section 11, Bloomfield Tp., Jackson County.

Limestone and limestone coal persistent along Dickason Run, west of Keystone. No. 5 coal pinched by sandstone above.

Forks of road on hill			
Sandstone, mainly		55	0
Shale, and covered		10	0
Sandstone, with parts covered		72	0
Sandstone, with pebbles		6	0
Coal blossom	No. 5	1	6
Clay, plastic		6	0
Clay, light, band of sandstone		11	0
Sandstone, shaly		10	0
Covered		4	0
Limestone, Ferriferous		2	0
Coal blossom	No. 4-A	4	0
Clay		3	0
Sandstone		35	0
Flood plain			

LOWER KITTANNING COAL NO. 5

/1/G

Stout 1915

372,000

File No 4065
Jackson ...
Bull. 21, p. 262

Section 69

Section 9, Bloomfield Tp., Jackson Co.

Limestone, Ferriferous		7	0
Draw slate			1
Coal		1	10
Clay clod			8
Coal	No. 4-A	1	4
Clay			2
oal			11
Clay		2	0

George Eagle mine, railroad mine.

S/D/G

Stout 1915

File No 4291
Wilkesville quad
X- 2,
Y- 371,2

Section 421

Ridgeland Coal Co. Abandoned railroad mine. Northeast part of section 9, Bloomfield Tp., Jackson County.

Limestone, Ferriferous, (seen)	3	0
Coal and clod, (reported)	5	0
Bottom of No. 4-A coal		
Clay	1	0
Sandstone, massive	45	0
Clay, (Black Flint horizon)	1	0
Sandstone	18	0
Shale	2	6
Sandstone, dark, shaly	1	0
Shale, black, fissle	6	0
Sandstone, and sandy shale with thin coal bands, No. 3-B	1	6
Shale, gray	4	0
Covered	6	0
Sandstone	15	0
Finger coals in sandstone above		
Shale, carbonaceous, black with coal bands	1	0
Clay, light	2	0

Stout 1915

File No 4566
[illegible]
Bull. 16, p. 201
X-1,9[illegible]
Y- 365,800

Section 70

Section 17, Bloomfield Tp. Central part. Jackson Co.

Limestone, Ferriferous	8	0
Draw slate		2
Coal	1	6
Clay		5
Coal	1	4
Clay sulfur		1
Coal	1	0
Clay	1	0

No 4a coal (Coal, Clay, Coal, Clay sulfur, Coal)

S/D/G

Section measured by R. E. Lamborn, Sept. 16, 1942 when collection limestone sample #391, Bulletin 49, p. 160.

A quarry in the Vanport limestone owned and operated by Iram Walton and sons is located just southwest of the diagonal road in the east central part of Section 17, Bloomfield Township. A section of the rocks exposed in the quarry follows:

		Ft.	In.
Shale, bluish gray............................		19	6
Limestone, bluish gray, dense...	Vanport	-	7
Limestone, bluish gray, somewhat laminated........................	Vanport	-	6
Limestone and black flint........	Vanport	-	7
Limestone, gray to light bluish or brownish gray, dense to finely crystalline....................	Vanport	2	9
Limestone, gray to brownish gray with occasional nodules of chert	Vanport	1	0
Limestone, bluish gray, dense to finely crystalline............	Vanport	1	8

745'
Field No.

File No. 4566

STRATIGRAPHIC SECTION

Page No. 2

			Ft.	In.
Coal, soft, shaly.....	Clarion or #4A	....	1	9
Shale parting.........		....	-	9
Coal..................		....	1	6
Parting...............		....	-	6
Coal		....	-	11

Bottom of exposure.

Stout 1915

File No 4067
[illegible]
Bull. 20, p. 242
X. 2,[illegible]
Y. 36[illegible]

Section 71

William Arthur, section 15, northern part, Bloomfield Tp., Jackson Co.

Ore, Ferriferous			6
Limestone, Ferriferous		7	6
Shale, black			3
Coal	No. 4-A	1	8
Clay			5
Coal		1	4
Clay			1
Coal		1	0
Clay			

Seen and reported benched for local use. No. 4 coal and limestone unsteady from Keystone to Ridgeland along Dicksen Run. No. 5 coal generally thin.

S/D/G